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שמה הוא Operation of Law בעל אמצאה מכח הדין
of an invention the title of which is Owner, by virtue of

מערכת לימוד עצמי אנדוסקופית


(בעברית)
(Hebrew)

ENDOSCOPIC TUTORIAL SYSTEM

(באנגלית)
(English)

hereby apply for a patent to be granted to me in respect thereof

מבקש בזאת כי ינתן לי עליה פטנט

• בקשת חלוקה - Application of Division	• בקשת פטנט מוסף - Application for Patent Addition	• דרישת דין קדימה Priority Claim		
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מערכת לימוד עצמי אנדוסקופית

ENDOSCOPIC TUTORIAL SYSTEM

ENDOSCOPIC TUTORIAL SYSTEM

FIELD AND BACKGROUND OF THE INVENTION

The present invention relates to a system and method for teaching and
5 training students in medical procedures, and in particular to a system and
method for training students in the procedure of flexible gastro-endoscopy.

Flexible gastro-endoscopy is an important medical tool for both surgical
and diagnostic procedures in the gastro-intestinal tract. Essentially, gastro-
endoscopy is performed by inserting an endoscope, which is a flexible tube,
10 into the gastro-intestinal tract, either through the mouth or the rectum of the
subject. The tube is manipulated by a trained physician through specialized
controls. The end of the tube which is inserted into the subject contains a
camera and one or more surgical tools, such as a clipper for removing tissue
samples from the gastro-intestinal tract. The physician must maneuver the tube
15 according to images of the gastro-intestinal tract received from the camera and
displayed on a video screen. The lack of direct visual feedback from the
gastro-intestinal tract is one factor which renders endoscopy a complex and
difficult procedure to master. Such lack of feedback also increases the
difficulty of hand-eye coordination and correct manipulation of the endoscopic
20 device. Thus, flexible gastro-endoscopy is a difficult procedure to both
perform and to learn.

Currently, students are taught to perform flexible gastro-endoscopy according to the traditional model for medical education, in which students observe and assist more experienced physicians. Unfortunately, such observation alone cannot provide the necessary training for such complicated medical procedures. Students may also perform procedures on animals and human cadavers, neither of which replicates the visual and tactile sensations of a live human patient. Thus, traditional medical training is not adequate for modern technologically complex medical procedures.

In an attempt to provide more realistic medical training for such procedures, simulation devices have been developed which attempt to replicate the tactile sensations and/or visual feedback for these procedures, in order to provide improved medical training without endangering human patients. An example of such a simulation device is disclosed in U.S. Patent No. 5,403,191, in which the disclosed device is a box containing simulated human organs. Various surgical laparoscopic procedures can be performed on the simulated organs. Visual feedback is provided by a system of mirrors. However, the system of both visual and tactile feedback is primitive in this device, and does not provide a true representation of the visual and tactile sensations which would accompany such surgical procedures in a human patient. Furthermore, the box itself is not a realistic representation of the three-dimensional structure of a human patient. Thus, the disclosed device is lacking in many important aspects and fails to meet the needs of a medical simulation device.

Attempts to provide a more realistic experience from a medical simulation devices are disclosed in PCT Patent Application Nos. WO 96/16389 and WO 95/02233. Both of these applications disclose a device for providing a simulation of the surgical procedure of laparoscopy. Both devices include a
5 mannequin in the shape of a human torso, with various points at which simulated surgical instruments are placed. However, the devices are limited in that the positions of the simulated surgical instruments are predetermined, which is not a realistic scenario. Furthermore, the visual feedback is based upon a stream of video images taken from actual surgical procedures.

10 However, such simple rendering of video images would result in inaccurate or unrealistic images as portions of the video data would need to be removed for greater processing speed. Alternatively, the video processing would consume such massive amounts of computational time and resources that the entire system would fail to respond in a realistic time period to the actions of the
15 student. At the very minimum, a dedicated graphics workstation would be required, rather than a personal computer (PC). Thus, neither reference teaches or discloses adequate visual processing for real time visual feedback of the simulated medical procedure.

Similarly, U.S. Patent No. 4,907,973 discloses a device for simulating
20 the medical procedure of flexible gastro-endoscopy. The disclosed device also suffers from the deficiencies of the above-referenced prior art devices, in that the visual feedback system is based upon rendering of video data taken from

actual endoscopic procedures. As noted previously, displaying such data would either require massive computational resources, or else would simply require too much time for a realistic visual feedback response. Thus, the disclosed device also suffers from the deficiencies of the prior art.

5 A truly useful and efficient medical simulation device for minimally invasive therapeutic procedures such as flexible gastro-endoscopy would give real time, accurate and realistic visual feedback of the procedure, and would also give realistic tactile feedback, so that the visual and tactile systems would be accurately linked for the simulation as for an actual medical procedure.

10 Unfortunately, such a simulation device is not currently taught or provided by the prior art.

 There is therefore a need for, and it would be useful to have, a method and a system to simulate a minimally invasive medical procedure such as flexible gastro-endoscopy, which would provide accurate, linked visual and
15 tactile feedback to the student and which would serve as a training resource for all aspects of the procedure.

SUMMARY OF THE INVENTION

 According to the present invention, there is provided a system for
20 simulating a medical procedure performed on a subject, comprising: (a) a simulated organ; (b) a simulated instrument for performing the medical procedure on the simulated organ; (c) a locator for determining a location of the

simulated instrument within the simulated organ; and (d) a visual display for displaying images from the medical procedure, such that the images simulate visual data received during the medical procedure as performed on an actual subject, the visual display including: (i) a three-dimensional model of the
5 simulated organ, the model being divided into a plurality of segments; (ii) a loader for selecting at least one of the plurality of segments for display, the at least one of the plurality of segments being selected according to the location of the simulated instrument within the simulated organ; (iii) a controller for selecting each image from the selected segment according to the location of the
10 simulated instrument; and (iv) a displayer for displaying the image according to the controller.

According to preferred embodiments of the present invention, the visual displayer further comprises: (v) a texture mapping engine for adding texture mapping to the selected image substantially before the selected image is
15 displayed by the displayer. Preferably, the texture mapping includes animation of random movement of the simulated instrument and of random movement of the simulated organ.

Preferably, the texture mapping includes images which are obtained from a performance of the medical procedure on the actual subject by first
20 recording the visual data during the performance and then selecting the images from the recorded visual data.

According to other preferred embodiments of the present invention, the displayer further displays a graphical user interface. Preferably, the graphical user interface displays tutorial information for aid in performing the medical procedure.

5 According to still other preferred embodiments of the present invention, the simulated organ is a gastro-intestinal tract. Preferably, the gastro-intestinal tract is constructed from a semi-flexible, smooth material. Also preferably, the simulated instrument is an endoscope, the endoscope featuring a sensor for determining a location of the sensor in the gastro-intestinal tract.

10 According to preferred embodiments of the present invention, there is further provided a tactile feedback mechanism for providing simulated tactile feedback according to the location of the tip of the endoscope. Preferably, the tactile feedback mechanism is contained in the gastro-intestinal tract, and the gastro-intestinal tract further comprises: (a) a plurality of servo-motors; (b) a
15 piston operated by each of the plurality of servo-motors, the piston contacting the semi-flexible material; and (c) a controller for controlling the plurality of servo-motors, such that a position of the piston is determined by the controller, and such that the position of the piston provides the tactile feedback.

 Alternatively and preferably, the tactile feedback mechanism is located
20 in the endoscope, and the endoscope further comprises: (a) a guiding sleeve connected to the tip of the endoscope; (b) at least one ball bearing attached to the guiding sleeve for rolling along an inner surface of the gastro-intestinal

tract; (c) at least one linear motor attached to the guiding sleeve; (d) a piston operated by the linear motor, the piston contacting the inner surface of the gastro-intestinal tract; and (e) a controller for controlling the linear motor, such that a position of the piston is determined by the controller, and such that the
5 position of the piston provides the tactile feedback.

Most preferably, the tactile feedback mechanism is operated according to tactile feedback obtained during the performance of the medical procedure on an actual subject, the tactile feedback being obtained through virtual reality gloves.

10 According to another embodiment of the present invention, there is provided a method for performing a simulated endoscopic procedure, the method comprising the steps of: (a) providing a system for performing the simulated endoscopic procedure, comprising: (i) a simulated gastro-intestinal tract; (ii) a simulated endoscope for performing the simulated endoscopic
15 procedure on the simulated gastro-intestinal tract; (iii) a locator for determining a location of the simulated endoscope within the simulated gastro-intestinal tract; and (iv) a visual display for displaying images according to the simulated endoscope within the simulated gastro-intestinal tract, such that the images simulate visual data received during an actual medical procedure as performed
20 on an actual subject, the visual display including: (1) a three-dimensional mathematical model of the simulated gastro-intestinal tract, the model being divided into a plurality of segments; (2) a loader for selecting at least one of the

plurality of segments for display, the at least one of the plurality of segments being selected according to the location of the simulated endoscope within the simulated gastro-intestinal tract; (3) a controller for selecting a simulated image from the segment according to the location of the simulated instrument; and (4) 5 a displayer for displaying the simulated image according to the controller, such that the simulated image is a displayed image; (b) inserting the simulated endoscope into the simulated gastro-intestinal tract; (c) receiving visual feedback according to the displayed image; and (d) receiving tactile feedback according to the location of the endoscope within the gastro-intestinal tract.

10 According to yet another embodiment of the present invention, there is provided a method for displaying simulated visual data of a medical procedure, the method comprising the steps of: (a) recording actual video data from a performance of an actual medical procedure on a living human patient; (b) abstracting a plurality of individual images from the actual video data; (c) 15 digitizing the plurality of individual images to form a plurality of digitized images; (d) selecting at least one of the plurality of digitized images to form a selected digitized image; (e) storing the selected digitized image as texture mapping data in a texture mapping database; (f) providing a three-dimensional mathematical model of an actual human colon, the model being divided into a plurality of segments; (g) selecting one of the plurality of segments from the 20 model for display; (h) overlaying the texture mapping data from the texture

mapping database onto the segment of the model to form at least one resultant image; and (i) displaying the resultant image.

Preferably, the texture mapping data further include animation. More preferably, the animation includes random movement of the simulated

5 instrument and random movement of the simulated organ.

Hereinafter, the term "simulated medical procedure" refers to the simulation of the medical procedure as performed through the system and method of the present invention. Hereinafter, the term "actual medical procedure" refers to the performance of the medical procedure on an actual,
10 living human patient with an actual endoscope, such that the medical procedure is "real" rather than "simulated".

Hereinafter, the term "endoscopy" includes, but is not limited to, the procedure of flexible gastro-endoscopy, as previously described, and medical diagnostic and surgical procedures in which an endoscope is inserted into the
15 mouth or the rectum of the subject for manipulation within the gastro-intestinal tract of the subject. Hereinafter, the term "subject" refers to the human or
lower mammal upon which the method and system of the present invention are performed or operated. Hereinafter, the term "student" refers to any human using the system of the present invention, being trained according to the present
20 invention or being taught according to the present invention including, but not limited to, students attending medical school or a university, a medical doctor, a trained gastro-enterologist or other trained medical specialist.

BRIEF DESCRIPTION OF THE DRAWINGS

The foregoing and other objects, aspects and advantages will be better understood from the following detailed description of a preferred embodiment of the invention with reference to the drawings, wherein:

FIG. 1 is an exemplary illustration of the system for medical simulation according to the present invention;

FIG. 2 is an exemplary illustration of a screen display according to the present invention;

FIG. 3 is a schematic block diagram of an exemplary visual processing and display system according to the present invention;

FIG. 4 is a schematic block diagram of an exemplary tutorial system according to the present invention;

FIGS. 5A and 5B illustrate an exemplary simulated gastro-intestinal tract according to the present invention;

FIGS. 6A-C illustrate various aspects of one embodiment of the force-feedback system according to the present invention; and

FIGS. 7A-7D illustrate a second embodiment of the force-feedback system according to the present invention.

BRIEF DESCRIPTION OF THE INVENTION

The present invention includes a method and a system to simulate the medical procedure of endoscopy, particularly of flexible gastro-endoscopy.

The system is designed to simulate the actual medical procedure of endoscopy as closely as possible by providing both a simulated medical instrument, and tactile and visual feedback as the simulated procedure is performed on the simulated patient. Although the discussion is directed toward the medical procedure of endoscopy, the present invention could also be employed to simulate other types of minimally invasive medical procedures.

The system of the present invention features both a physical model and a virtual model for the simulation of the medical procedure of endoscopy. The physical model includes a mannequin into which the simulated endoscope is inserted. A simulated gastro-intestinal tract is located within the mannequin, which includes a simulated rectum and a simulated colon. The simulated endoscope is inserted into the simulated rectum and then into the simulated colon. The simulated gastro-intestinal tract provides realistic tactile feedback according to the movement of the simulated endoscope within the simulated colon.

The virtual model provides a "virtual reality" for the simulation of images from the endoscope. In an actual endoscopic medical procedure, a camera at the tip of the actual endoscope returns images from the colon of the human patient. These images are then viewed by the physician performing the endoscopic procedure, thereby providing visual feedback to the physician. The

system of the present invention provides a "virtual reality" for the realistic simulation of this visual feedback. This virtual reality enables the real-time display of realistic images of the gastro-intestinal tract on a video monitor according to the manipulations of the simulated endoscope, preferably in such a manner that the tactile and visual feedback are linked as they would be in a human patient.

The virtual reality has two main components: a three-dimensional, mathematical model of the colon, and a database of enhanced digitized images derived from actual visual data obtained from an actual endoscopic procedure. These two components are combined to provide realistic visual feedback by using the enhanced images as texture mapping to overlay the mathematical model of the colon, thereby closely simulating images obtained from the actual procedure.

The virtual reality of the colon is particularly advantageous for simulating images because it does not rely on video streams, which require massive computational power for real-time display of visual feedback. In addition, video streams provide only a predetermined flow of images and cannot provide visual data with six degrees of freedom in real time. Furthermore, the virtual reality of the present invention does not rely merely on a mathematical model of the colon, which cannot capture the irregularities and subtle visual features of an actual colon from a human patient. Thus, the virtual

reality of the colon provides the best simulation of realistic images in real time for visual feedback.

DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

5 An object of this invention is the provision of a method and a system to simulate the procedure of endoscopy, particularly of flexible gastro-endoscopy. The system includes a mannequin into which the simulated endoscope is inserted. Visual feedback is provided through a video monitor, which displays realistic images in real time, according to the manipulations of the simulated
10 endoscope. Realistic tactile feedback is also provided, preferably in such a manner that the tactile and visual feedback are linked as they would be in a human patient. Another object of the present invention is the provision of a tutorial system for training students and testing their performance. Thus, the system and method of the present invention provide a realistic simulation of the
15 medical procedure of endoscopy for training and testing students.

 The principles and operation of a method and a system for communication according to the present invention may be better understood with reference to the drawings and the accompanying description, it being understood that these drawings are given for illustrative purposes only and are
20 not meant to be limiting.

 Referring now to the drawings, Figure 1 depicts an exemplary, illustrative system for medical simulation according to the present invention. A

system 10 includes a mannequin 12 representing the subject on which the procedure is to be performed, a simulated endoscope 14 and a computer 16 with a video monitor 18. A student 20 is shown interacting with system 10 by manipulating simulated endoscope 14 within mannequin 12. As further
5 illustrated in Figures 5A and 5B below, mannequin 12 includes a simulated organ into which simulated endoscope 14 is inserted. As student 20 manipulates simulated endoscope 14, tactile and visual feedback are determined according to the position of endoscope 14 within the simulated organ (not shown). The visual feedback are provided in the form of a display on video
10 monitor 18. The necessary data calculations are performed by computer 16, so that realistic tactile and visual feedback are provided to student 20.

Figure 2 is an exemplary illustration of a screen display shown on monitor 18. A screen display 22 includes a feedback image 24. Feedback image 24 represents the visual image as seen if the endoscope were inserted
15 into a living human patient. Feedback image 24 is an accurate and realistic simulation of the visual data that would be received from that portion of the gastro-intestinal tract in the living human patient. Although feedback image 24 is shown as a static image, it is understood that this is for illustrative purposes only and the actual visual feedback data would be in the form of a substantially
20 continuous flow of simulated images based upon actual video stream data obtained from an actual endoscopic procedure. Thus, the flow of images

represented by feedback image 24 gives the student (not shown) realistic visual feedback.

In addition, screen display 22 preferably includes a number of GUI (graphic user interface) features related to the preferred tutorial functions of the present invention. For example, a tracking display 26 explicitly shows the location of the simulated endoscope within the simulated gastro-intestinal tract. Tracking display 26 includes a schematic gastro-intestinal tract 28, into which a schematic endoscope 30 has been inserted. Preferably, tracking display 26 can be enabled or disabled, so that the student can only see tracking display 26 if the tracking function is enabled.

Additional, optional but preferred features of screen display 22 include the provision of a "help" button 32, which upon activation could cause the display of such helpful information as a guide to the controls of the endoscope. Similarly, a preferred "hint" button 34 would give the student one or more suggestions on how to continue the performance of the medical procedure. A preferred "patient history" button 36 would cause screen display 22 to show information related to one of a selection of simulated "patient histories", which could be of help to the student in deciding upon a further action. Finally, a preferred "performance" button 38 would cause screen display 22 to display a review and rating of the performance of the student. All of these functions are part of the preferred embodiment of a tutorial system for training a student in the medical procedure of endoscopy, as described in further detail in Figure 4.

Figures 3A and 3B are schematic block diagrams of an exemplary visual processing and display system and method according to the present invention.

Figure 3A is a flow chart of the method for visual processing and display according to the present invention, and is intended as a summary of the method employed by the system of Figure 3B. Further details concerning particular aspects of the method are described below with reference to Figure 3B. In step one, actual video data are recorded onto videotape during the performance of the actual medical procedure of endoscopy on a living human patient. In step two, individual images are abstracted with a framegrabber and then digitized. In step three, the digitized images are preferably selected for clarity and lack of visual artifacts, and are then stored in a texture mapping database. More preferably, the digitized images are enhanced before being stored. Most preferably, the texture mapping also include animation. Such animation could simulate effects such as random vibration of the tissue of the colon or of the endoscope, as well as such events as liquid flowing downward due to the influence of gravity.

In step four, a portion or "chunk" of a three-dimensional mathematical model of the human colon is loaded for display. In step five, texture mapping from the database is overlaid onto the chunk of the model. Preferably, such texture mapping includes both the digitized images and additional animation. In step six, the resultant images are displayed. As noted previously, the images

are displayed in a continuous flow according to the location of the simulated endoscope within the simulated gastrointestinal tract.

Figure 3B shows the visual processing and display system according to the present invention in more detail. A visual processing and display system 40 includes screen display 22 for displaying the processed visual data. The visual data are constructed as follows. First, data are recorded from actual gastro-endoscopic procedures onto videotape, as shown in a recording block 42. The data are preferably stored on Super-VHF videotape in order to obtain the highest quality representation of the visual images displayed on the screen during the actual endoscopic procedure, as shown in block 44. Next, at least a portion of the frames of the videotape, and preferably substantially all the frames, are abstracted individually by a frame-grabber 46 to form digitized images. Individual digitized images can then be selected for clarity and lack of artifacts such as reflections from the endoscopic apparatus itself. The images in the selected frames are then preferably enhanced and added to a texture mapping database 48.

Preferably, two types of texture mapping are stored in the database. The first type of texture mapping is intended to enhance the realistic visual aspects of the images, for example by removing visual artifacts. The second type of texture mapping is intended to simulate the behavior of a live organ and a real endoscope, as represented by block 50. During actual endoscopic procedures on a living human patient, the tissue of the colon moves somewhat, and the

endoscope itself vibrates and wobbles. This movement is simulated visually by the addition of random animation of the images, and also by the addition of such effects as liquid flowing downward due to the influence of gravity. Such animation enhances the realistic nature of the visual representation of the colon.

5 In order for the enhanced images to be correctly displayed, the images must correspond to the manipulation and location of the simulated endoscope within the simulated colon. In particular, the texture mapping of the images should correspond to the location of the endoscope within the colon. Such correspondence between the location of the endoscope within the colon and the
10 texture mapping is provided by a texture mapping engine 52. The texture mapping data is then readily accessed by the display portion of visual system 40, as shown by block 54.

 However, as noted for previous prior art devices, simply reproducing the selected enhanced frames in a massive video stream would quickly overwhelm
15 the computational resources and cause the visual display to become unsynchronized from the physical location of the simulated endoscope.

 Furthermore, such a video stream would not enable the correct display of images according to the movement of the endoscope, which preferably has six degrees of freedom. Thus, mere reproduction is not sufficient to ensure
20 realistic images, even when mapped onto a three-dimensional surface.

 Preferably, visual processing and display system 40 includes a three-dimensional mathematical model of at least a portion of the gastro-intestinal

tract 56. For the purposes of discussion, model 56 is herein described as a three-dimensional model of the colon, it being understood that this is not meant to be limiting in any way. An important feature of model 56 is the division of the modeled colon into a plurality of segments, preferably six segments 58.

5 The division is made linearly, since the spatial movement of the simulated endoscope is limited. In other words, the simulated endoscope cannot "jump" from one portion of the colon to another, but must instead proceed in a linear fashion along the simulated colon. In addition, the simulated endoscope can only be moved at a finite speed through the simulated colon. Thus, the
10 endoscope must pass through each segment 58 of the three-dimensional model of the colon in sequence at a known, limited speed.

The consequences of such a division of model 56 into six segments 58 is that only one segment 58 needs to be processed in any given moment, although a plurality of such segments 58 could be processed substantially
15 simultaneously if the computing resources were available. Furthermore, the division reduces the visual processing into a much more manageable task, since model 56 includes a total of about 282,000 polygons in the preferred embodiment, but each segment 58 has only about 44,000 polygons.

As the simulated endoscope moves along the simulated colon, the
20 location of the endoscope is given to a locator 60, described in further detail below. Locator 60 then instructs an object loader 62 to load the relevant segment 58 for access by visual system 40, as shown in block 54 and

previously described. In the preferred embodiment shown, preferably three segments 58 are ready for access by object loader 62 at any given moment. The specific segment 58 in which the endoscope is currently located is preferably held in DRAM or RAM, in combination with the texture mapping described previously. The next segment 58 and the preceding segment 58 are also kept easily accessible, although not necessarily in RAM or DRAM.

Preferably, the display of each image from specific segment 58 into which the simulated endoscope has entered is optimized by a segment optimizer 64. Segment optimizer 64 receives information from locator 60, as well as the series of images obtained from overlaying the texture mapping onto the relevant segment 58, and then feeds each specific image to a display manager 66 for display on screen display 22.

In addition, display manager 66 is assisted by a real-time viewer 68, preferably implemented in Direct 3D™ (Microsoft Inc., Seattle, Washington). Real-time viewer 68 provides the necessary software support to communicate with a graphics card 70 for actual display of the images on screen display 22. Although graphics card 70 can be of any suitable manufacture, preferably graphics card 70 has at least 8, and more preferably 16, Mb of VRAM for optimal performance. An example of a suitable graphics card 70 is the 3Dfx Voodoo Rush™ card. Preferably, the performance of real-time viewer 68 is enhanced by a math optimizer 72, preferably implemented in Visual C++.

The interaction between segment optimizer 64 and display manager 66 on the one hand, and locator 60 on the other, is provided through a software interface 74, preferably implemented as a Direct Plug-in™ (Microsoft Inc., Seattle, Washington). Software interface 74 enables locator 60 to communicate with the other components of visual system 40, in order to provide information regarding the location of the endoscope within the colon.

In preferred embodiments of the present invention, locator 60 includes a sensor 76, which can be obtained from Ascension Technology Corp., for example. Sensor 76 senses positional information from within a simulated organ 77, which is described herein as a colon for the purposes of discussion and is not meant to be limiting. Sensor 76 is controlled by a control unit 82. The positional information is then relayed to a CPU controller 78, which is connected to a servo-motor 80 (Haydon Switch and Instrument Co.). As the simulated endoscope moves through the colon, the endoscope contacts different portions of the colon (not shown; see Figures 5 and 6 below). Tactile feedback is provided by each servo-motor 80 in turn, which manipulates the material of the colon.

Visual system 40 also includes a user interface 84, preferably implemented in Visual C++. User interface 84 includes the GUI features described previously for Figure 2. In addition, user interface 84 enables visual system 40 to interact with the preferred feature of a network interface 86, for example, so that other students can view screen display 22 over a network.

User interface 84 also permits the tutorial functions of at least one, and preferably a plurality of, tutorial modules 88 to be activated. Tutorial module 88 could include a particular scenario, such as a subject with colon cancer, so that different types of diagnostic and medical challenges could be presented to the student. The student would then need to respond correctly to the presented scenario.

An example of the tutorial system is illustrated in more detail in the block diagram of Figure 4. A tutorial system 90 starts as shown in block 92. Next, the user must select whether actual interaction with the simulated endoscope is desired, or if the user prefers to receive tutoring in the theory of endoscopy, as shown in a block 94. The next display asks if the user is new, as shown in a block 96. If the answer is "yes", the user is requested to enter certain information, as shown by block 98. If the answer is "no", the user is requested to enter identification information, such as user name or identification number, as shown in block 100.

Next, the user must select the type of tutoring. For example, the user could select tutoring by subject 102, tutoring by procedures 104 or tutoring by case studies 106. Tutoring by subject 102 includes, but is not limited to, such subjects as basic manipulation of the endoscope, biopsy and polypectomy. Tutoring by subject 102 includes on-screen support, as shown in block 108.

Tutoring by case studies 106 can be selected both according to case number and according to the level of the desired cases, such as beginner,

intermediate and expert. Preferably, individual case studies could be created by a teacher or professor, by combining features of various stored cases. For example, a professor could create a case history appropriate for a 20 year old male with colitis, so that the student would then be able to practice endoscopy on such a patient. Thus, tutoring system 90 preferably has the flexibility to enable many different types of "patients" to be studied.

If desired, on-screen support can be provided for both tutoring by case studies 106 and tutoring by procedures 104, as shown in block 110. If on-screen support is not desired, the user can indicate whether the tutoring session is actually an official test, as shown in block 112. Thus, tutoring system 90 includes both the ability to teach and the ability to test the student.

Figures 5A and 5B illustrate the mechanical aspects of an exemplary simulated gastro-intestinal tract according to the present invention. A cut-away view of a mannequin 114 is shown in Figure 5A. Preferably, mannequin 114 is about one meter wide, which is within the dimensions of an actual human subject. A simulated gastro-intestinal tract 116 is shown within mannequin 114. For the purposes of clarity, simulated gastro-intestinal tract 116 includes only the colon, it being understood that this is not meant to be limiting in any way. Simulated gastro-intestinal tract 116 is connected to a transmitter 118 and a signal processing device 120, also placed within mannequin 114. As shown, a simulated endoscope 122 can be inserted into mannequin 114 through an opening 124. In this case, since the simulation is for

endoscopy of the colon of the subject, opening 124 simulates the rectum of the subject.

Simulated endoscope 122 can be maneuvered left, right, up and down. Preferably, simulated endoscope 122 is about 1800 cm long, similar to the
5 length of a real endoscope. Also preferably, the diameter of the tip of simulated endoscope 122 is about 13.4 mm, while the remainder of endoscope 122 has a diameter of about 10.2 mm, again similar to the dimensions of a real endoscope.

Once simulated endoscope 122 is inserted into simulated gastro-
10 intestinal tract 116, sensor 76 on the tip of simulated endoscope 122 is able to detect the location of simulated endoscope 122. Sensor 76 preferably has three degrees of freedom, more preferably six degrees of freedom for effective simulation of manipulation of endoscope 122. If sensor 76 has six degrees of freedom, the detected directions of orientation include the Cartesian coordinates
15 X, Y, Z, as well as roll, elevation and azimuth. In addition, sensor 76 preferably includes a sensor transmitter 126, so that the precise angle and location of sensor 76 can be determined relative to gastro-intestinal tract 116. Sensor transmitter 126 transmits data to signal processing device 120, which then analyzes and processes the signal. The processed signal is then given to
20 transmitter 118 for transmission to an electronics unit 128 and a DC drive unit 130. The signal is converted by DC drive unit 130 and passed to electronics unit 128. Electronics unit 128 then sends the position and orientation of sensor

76 to software interface 74, so that the remainder of the display system is able to use the information to display the correct images on display screen 22 for visual feedback.

The present invention provides both visual feedback and tactile
5 feedback. Tactile feedback can be provided through the exertion of forces on simulated endoscope 122 by simulated gastro-intestinal tract 116, as shown in Figures 6A-6C. Alternatively, tactile feedback could be provided by the mechanical action of simulated endoscope 122, as shown in Figures 7A-7D. For the first embodiment, preferably simulated gastro-intestinal tract 116 is
10 constructed from semi-flexible material, which gives the feel of a smooth and wet material. Of course, the actual sensations of sliding along a semi-flexible, smooth, wet material can also be provided through the mechanism of endoscope 122 itself, as in the second embodiment.

An additional embodiment of gastro-intestinal tract 116, in which tract
15 116 is placed within a box 132 rather than within mannequin 114, is shown in Figure 5B. The advantage of box 132 is that box 132 could serve to contain any radiowaves, so that the mechanism of gastro-intestinal tract 116 could be controlled by transmission of radiowaves, for example. Since certain medical equipment is highly sensitive to these radiowaves, they would need to remain
20 within mannequin 114. Box 132 would therefore act to insulate gastro-intestinal tract 116 from the external environment outside the mannequin. Details of gastro-intestinal tract 116 are more readily seen in Figure 6A, it

being understood that Figures 5A, 5B and 6A illustrate the same gastro-intestinal tract 116.

Figure 6A shows gastro-intestinal tract 116 according to the first embodiment, in which tactile feedback is provided by forces acting on
5 simulated endoscope 122 by a mechanism contained within gastro-intestinal tract 116 itself. Simulated gastro-intestinal tract 116 is made from a semi-flexible material. A plurality of motion boxes 134 are disposed at intervals along the outer surface of gastro-intestinal tract 116. For the purposes of illustration, seven motion boxes 134 are shown. Each motion box 134, shown
10 in greater detail in Figure 6B, has at least one, and preferably a plurality of, servo-motors 80, preferably linear motors.

Each servo-motor 80 is connected to a piston 136. The detail of piston 136 is shown enlarged in Figure 6B. Each piston 136 is connected to a foot 138, which contacts a portion of the material of the external surface of gastro-
15 intestinal tract 116. Preferably, foot 138 is actually attached to the portion of the material of the external surface, for easier manipulation of the material.

Preferably, there are two different types of pistons 136. The first type, of which two are shown for illustrative purposes, is a vertical force piston 140 for causing vertical movement of a portion of the external surface of gastro-
20 intestinal tract 116. The second type, of which one is shown for illustrative purposes, is a horizontal force piston 142 for causing horizontal movement of a portion of the external surface of gastro-intestinal tract 116. In the preferred

embodiment shown, servo-motor 80 is an oscillating motor placed directly against the material of gastro-intestinal tract 116, so that horizontal force piston 142 includes the motor alone, without a structure similar to vertical force piston 140. Since each piston 136 has an associated servo-motor 80, the necessary
5 vertical and horizontal movement of the external surface of gastro-intestinal tract 116 can be precisely determined by the activity of servo-motor 80.

Each piston 136, or preferably attached foot 138, contacts the material of gastro-intestinal tract 116 in order to manipulate this material to exert a force against the endoscope (not shown). For example, as shown in Figure 6B, a first
10 vertical force piston 144 could be moved closer to servo-motor 80, while a second vertical force piston 146 is moved away from servo-motor 80. These movements alter the position of the material of gastro-intestinal tract 116, causing forces to be exerted against the simulated endoscope similar or identical to those felt during an actual endoscopic procedure. In addition,
15 horizontal force piston 142, which is preferably an oscillating servo-motor alone as shown, moves horizontally to provide more delicate fine-tuning of the tactile feedback sensations. Since servo-motors 80 are disposed over the three-dimensional surface of gastro-intestinal tract 116, the force on the endoscope can be exerted in three dimensions.

20 The activity of servo-motor 80 is in turn controlled by digital controller 82. Digital controller 82 can be a card inserted within the PC computer which is performing the requisite calculations required for the simulation of the

medical process. Software operated by the PC computer uses positional and orientation information from sensor 76 on simulated endoscope 122 to determine the position of simulated endoscope 122. Next, the software sends instructions to digital controller 82 according to the desired tactile sensations
5 which should be felt by the operator of simulated endoscope 122 at that particular position within simulated gastro-intestinal tract 116. Digital controller 82 then causes at least one servo-motor 80 to move the associated piston 136 as necessary to provide the tactile feedback sensations.

Digital controller 82 can be connected to servo-motors 80 through some
10 type of radiation, such as infra-red light. However, the limitations on radiation of certain wavelengths, such as radiowaves, within the hospital or medical environment, make a connection by an actual wire running from digital controller 82 to each servo-motor 80 more preferable. In the exemplary embodiment shown in Figure 6B, each servo-motor 80 is connected to a motion
15 box controller 144 by a wire. Motion box controller 144 is then preferably connected to digital controller 82 by a single wire (not shown). This configuration limits the number of individual connections made to digital controller 82 for greater efficiency.

Figure-6C shows an enlarged cut-away view of servo-motor 80, which as
20 noted previously is preferably a linear motor. Preferably, servo-motor 80 is about 100 mm wide and 45 mm tall.

Figures 7A-7D show a second embodiment of the mechanism for providing tactile feedback. In this embodiment, the mechanism is contained within the simulated endoscope itself, rather than the simulated gastro-intestinal tract. Similar to the previous embodiment, the simulated gastro-intestinal tract could be contained within a substantially life-size mannequin with an opening for simulating the rectum. Furthermore, from the viewpoint of the student or other individual operating the simulated endoscope, both embodiments should give a suitable simulation of the medical procedure. However, as detailed below, the actual mechanism of providing the tactile portion of the simulation differs.

Figure 7A shows the second embodiment of a simulated endoscope 146. The movements and actions of simulated endoscope 146 are controlled through a set of controls 148. The tip of simulated endoscope 146 is contained within a guiding sleeve 150. Guiding sleeve 150, shown in greater detail in Figure 7B, preferably remains within the simulated gastro-intestinal tract (not shown; see Figure 7C) in order to maintain a realistic visual appearance of simulated endoscope 146 before insertion into the mannequin (not shown). Preferably, the tip of endoscope 146 has a metal bracket 152 attached, which could be labeled with the word "sample" or with another label in order to clarify that endoscope 146 is only a simulation and not an actual medical instrument. The inside of guiding sleeve 150 is preferably magnetized, for example with an electric current. Thus, when the tip of endoscope 146 is inserted in the

mannequin, metal bracket 152 is attracted to guiding sleeve 150 so that guiding sleeve 150 remains attached to the tip of endoscope 146.

Guiding sleeve 150 has at least one, and preferably a plurality of, ball bearings 154 attached to the exterior surface of guiding sleeve 150. In addition, 5 guiding sleeve 150 has at least one, and preferably a plurality of, attached plungers 156. As shown in the detailed view in Figure 7B, one end of guiding sleeve 150 preferably features a section of flexible material 158. As shown, the tip of endoscope 146 is preferably inserted through guiding sleeve 150. The tip of endoscope 146 features sensor 76, as for the previous embodiment of the 10 simulated endoscope.

Figure 7C shows simulated endoscope 146 after insertion within the second embodiment of a simulated gastro-intestinal tract 160. Simulated gastro-intestinal tract 160 is preferably constructed from a rigid material. In addition, simulated gastro-intestinal tract 160 preferably has the general 15 anatomical shape and features of an actual gastro-intestinal tract for two reasons. First, the general anatomical shape can be more easily contained within the mannequin because of its bends and turns. Second, the general anatomical shape can provide gross tactile feedback. For example, as any endoscope is inserted more deeply into the colon, the shape of the colon causes 20 the tactile sensations to be altered as the endoscope moves around a bend in the colon. Thus, the general anatomical shape is more useful for an effective simulation.

As endoscope 146 moves within simulated gastro-intestinal tract 160, guiding sleeve 150 enables the operator to receive tactile feedback as follows. Ball bearings 154 roll along the interior surface of gastro-intestinal tract 160. Each ball bearing 154 has five degrees of freedom for movement. Each plunger 156 is connected to a linear motor 162, as shown in cross-section in Figure 7D. Linear motor 162 is controlled in a similar fashion as the servo-motor of the previous embodiment. Upon receipt of signals from the computer, linear motor 162 causes plunger 156 to move vertically, thereby causing the operator of simulated endoscope 146 to receive tactile feedback sensations. Thus, guiding sleeve 150 causes tactile feedback to be transmitted back through endoscope 146.

In addition, as noted above guiding sleeve 150 preferably has section of flexible material 158. Section of flexible material 158 causes the tip of endoscope 146 to encounter some resistance under certain circumstances, such as when the tip is bent back on itself. Thus, section of flexible material 158 restrains movement of the tip from certain angles.

The particular advantages of this second embodiment is that the majority of tactile sensations are determined by the endoscope itself, so that they can be more easily controlled from the PC computer. Furthermore, such anatomical features as a fistula can be added according to instructions from the computer, without the necessity of changing the physical model of the simulated gastro-intestinal tract. Additionally, under certain circumstances the tissue of the

actual colon will force the endoscope backwards, a situation which can be more easily replicated in the second embodiment. Thus, the second embodiment of the simulated gastro-intestinal tract and endoscope is more flexible in terms of replicating a greater variety of anatomical features and conditions.

5 In order to accurately replicate the tactile sensations of an actual endoscope during a medical procedure, these sensations must be accurately obtained during an endoscopic procedure in an actual living patient. For example, such tactile sensations could be collected from a physician performing the endoscopic procedure while wearing virtual reality gloves, such as the
10 DataGloves™ Tracking VR System (Greenleaf Medical Systems). These gloves are known for being able to register data regarding tactile sensations and feedback as experienced by the physician during the actual endoscopic procedure. Such actual data are important because the tactile sensations change during the course of the procedure. For example, correlation between the
15 movement of the endoscope and the visual display is gradually decreased as the endoscope is inserted deeper into the gastro-intestinal tract. Thus, the collection of actual data is an important step in the provision of an accurate, realistic endoscopic simulator.

 Finally, according to another preferred embodiment of the present
20 invention there is provided a simulated biopsy device (not shown). This biopsy device would simulate the actual biopsy device used to retrieve tissue samples from the gastro-intestinal tract during endoscopy. The actual biopsy device is

contained within the endoscope. When the operator of the endoscope wishes to take a sample, the biopsy device emerges from the tip of the endoscope, at which point it is visible on the display screen. The jaws of the biopsy device are then opened and pushed onto the tissue. The jaws are then closed, and the
5 biopsy device retracted. The removal of the tissue causes pools of blood to appear as the remaining tissue bleeds.

Similarly, the simulated biopsy device will only appear on the display screen of the present invention when the operator of the simulated endoscope causes the simulated biopsy device to emerge. The jaws of the biopsy device
10 are preferably rendered as animation, more preferably in relatively high resolution because the jaws are small, so that a high resolution would not prove unduly taxing for the PC computer. The bleeding of the tissue and the resultant pools of blood will also be animated.

15 It will be appreciated that the above descriptions are intended only to serve as examples, and that many other embodiments are possible within the spirit and the scope of the present invention.

WHAT IS CLAIMED:

1. A system for performing a simulated medical procedure, comprising:
 - (a) a simulated organ;
 - (b) a simulated instrument for performing the simulated medical procedure on said simulated organ;
 - (c) a locator for determining a location of said simulated instrument within said simulated organ; and
 - (d) a visual display for displaying images according to said location of said simulated instrument within said simulated organ, such that said images simulate actual visual data received during an actual medical procedure as performed on an actual subject, said visual display including:
 - (i) a three-dimensional mathematical model of said simulated organ, said model being divided into a plurality of segments;
 - (ii) a loader for selecting at least one of said plurality of segments for display, said at least one of said plurality of segments being selected according to said location of said simulated instrument within said simulated organ;

- (iii) a controller for selecting a simulated image from said segment according to said location of said simulated instrument; and
- (iv) a displayer for displaying said simulated image.

2. The system of claim 1, wherein said visual displayer further comprises:

- (v) a texture mapping database for storing texture mapping data; and
- (vi) a texture mapping engine for overlaying said simulated image with said texture mapping data substantially before said simulated image is displayed by said displayer.

3. The system of claim 2, wherein said texture mapping is animation of random movement of said simulated instrument and random movement of said simulated organ.

4. The system of claim 1, wherein said texture mapping includes images obtained from performing said actual medical procedure on said actual subject.

5. The system of claim 4, wherein said images are obtained by first recording said visual data during said performance and then selecting said images from said recorded visual data.

6. The system of claim 1, wherein said displayer further displays a graphical user interface.

7. The system of claim 6, wherein said graphical user interface displays tutorial information for aid in performing the medical procedure.

8. The system of claim 1, wherein said simulated organ is a gastro-intestinal tract.

9. The system of claim 8, wherein said gastro-intestinal tract is constructed from a semi-flexible, smooth material.

10. The system of claim 8, wherein said simulated instrument is an endoscope, said endoscope featuring a sensor for determining a location of said sensor in said gastro-intestinal tract.

11. The system of claim 10, further comprising a tactile feedback mechanism for providing simulated tactile feedback according to said location of said tip of said endoscope.

12. The system of claim 11, wherein said tactile feedback mechanism is contained in said gastro-intestinal tract, and said gastro-intestinal tract further comprises:

- (a) a plurality of servo-motors;
- (b) a piston operated by each of said plurality of servo-motors, said piston contacting said semi-flexible material; and
- (c) a controller for controlling said plurality of servo-motors, such that a position of said piston is determined by said controller, and such that said position of said piston provides said tactile feedback.

13. The system of claim 11, wherein said tactile feedback mechanism is located in said endoscope, and said endoscope further comprises:

- (a) a guiding sleeve connected to said tip of said endoscope;
- (b) at least one ball bearing attached to said guiding sleeve for rolling along an inner surface of said gastro-intestinal tract;
- (c) at least one linear motor attached to said guiding sleeve;

- (d) a piston operated by said linear motor, said piston contacting said inner surface of said gastro-intestinal tract; and
- (e) a controller for controlling said linear motor, such that a position of said piston is determined by said controller, and such that said position of said piston provides said tactile feedback.

14. The system of claim 11, wherein said tactile feedback mechanism is operated according to tactile feedback obtained during said performance of the medical procedure on an actual subject, said tactile feedback being obtained through virtual reality gloves.

15. A method for performing a simulated endoscopic procedure, comprising the steps of:

- (a) providing a system for performing the simulated endoscopic procedure, comprising:
 - (i) a simulated gastro-intestinal tract;
 - (ii) a simulated endoscope for performing the simulated endoscopic procedure on said simulated gastro-intestinal tract;
 - (iii) a locator for determining a location of said simulated endoscope within said simulated gastro-intestinal tract; and

- (iv) a visual display for displaying images according to said simulated endoscope within said simulated gastro-intestinal tract, such that said images simulate visual data received during an actual medical procedure as performed on an actual subject, said visual display including:
 - (1) a three-dimensional mathematical model of said simulated gastro-intestinal tract, said model being divided into a plurality of segments;
 - (2) a loader for selecting at least one of said plurality of segments for display, said at least one of said plurality of segments being selected according to said location of said simulated endoscope within said simulated gastro-intestinal tract;
 - (3) a controller for selecting a simulated image from said segment according to said location of said simulated instrument; and
 - (4) a displayer for displaying said simulated image according to said controller, such that said simulated image is a displayed image;
- (b) inserting said simulated endoscope into said simulated gastro-intestinal tract;
- (c) receiving visual feedback according to said displayed image; and

- (d) receiving tactile feedback according to said location of said endoscope within said gastro-intestinal tract.


16. A method for displaying simulated visual data of a medical procedure, the method comprising the steps of:

- (a) recording actual video data from a performance of an actual medical procedure on a living human patient;
- (b) abstracting a plurality of individual images from said actual video data;
- (c) digitizing said plurality of individual images to form a plurality of digitized images;
- (d) selecting at least one of said plurality of digitized images to form a selected digitized image;
- (e) storing said selected digitized image as texture mapping data in a texture mapping database;
- (f) providing a three-dimensional mathematical model of an actual human colon, said model being divided into a plurality of segments;
- (g) selecting one of said plurality of segments from said model for display;

- (h) overlaying said texture mapping data from said texture mapping database onto said segment of said model to form at least one resultant image; and
- (i) displaying said resultant image.

17. The method of claim 16, wherein said texture mapping data further include animation.

18. The method of claim 17, wherein said animation includes random movement of said simulated instrument and random movement of said simulated organ.



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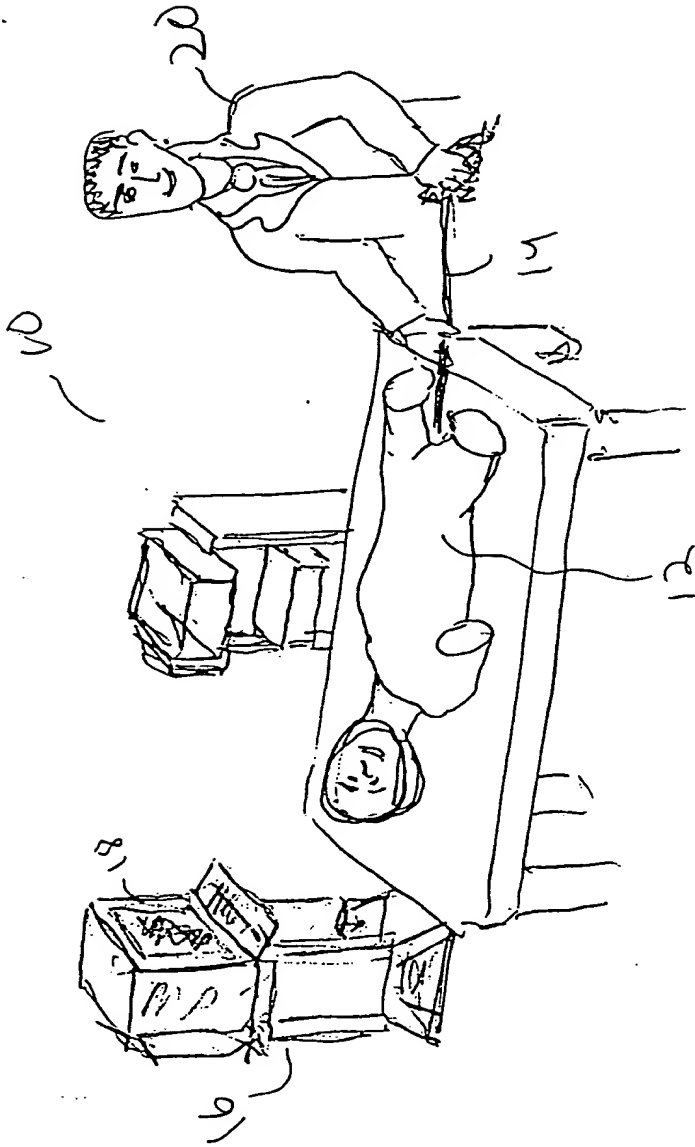


Figure 1

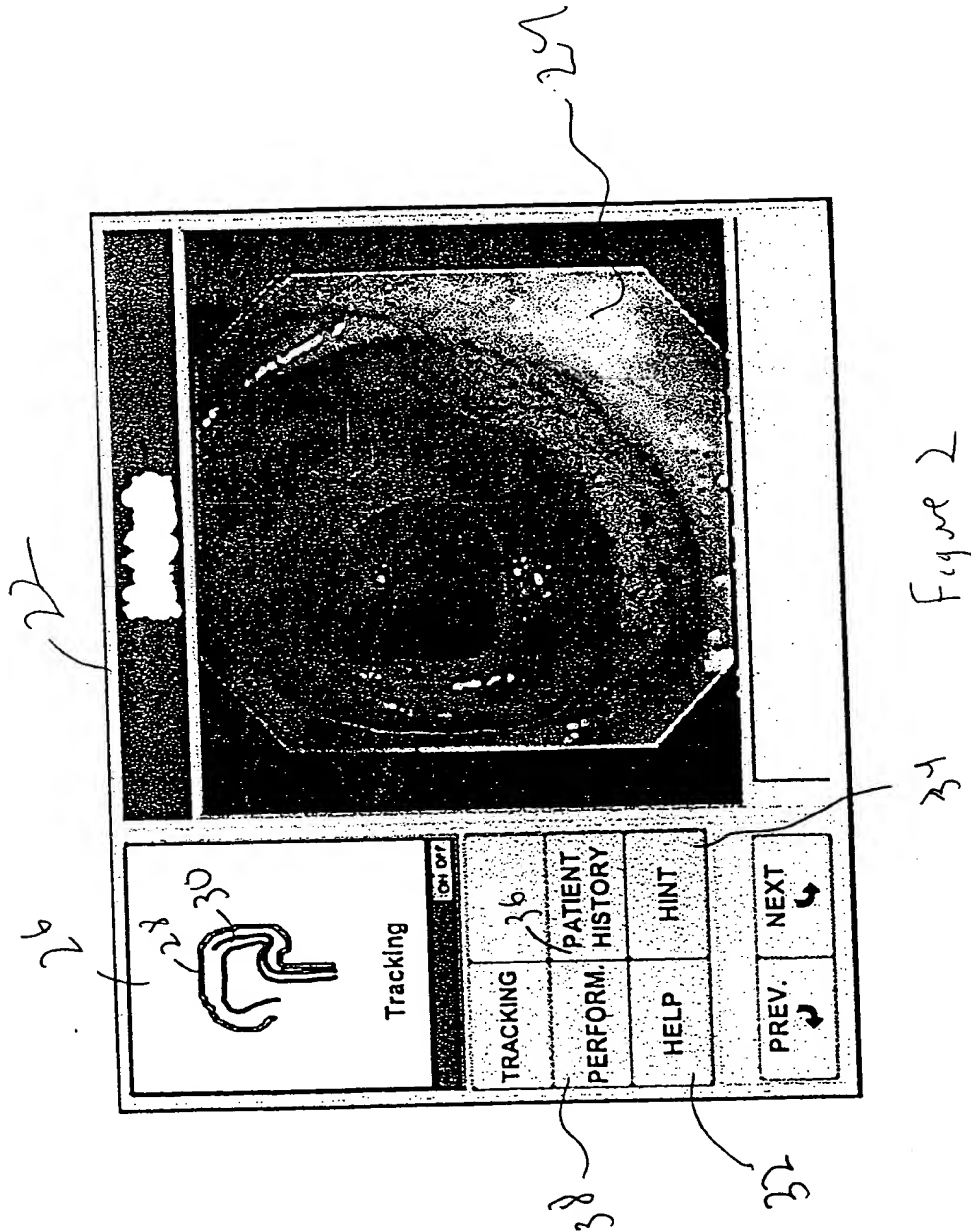
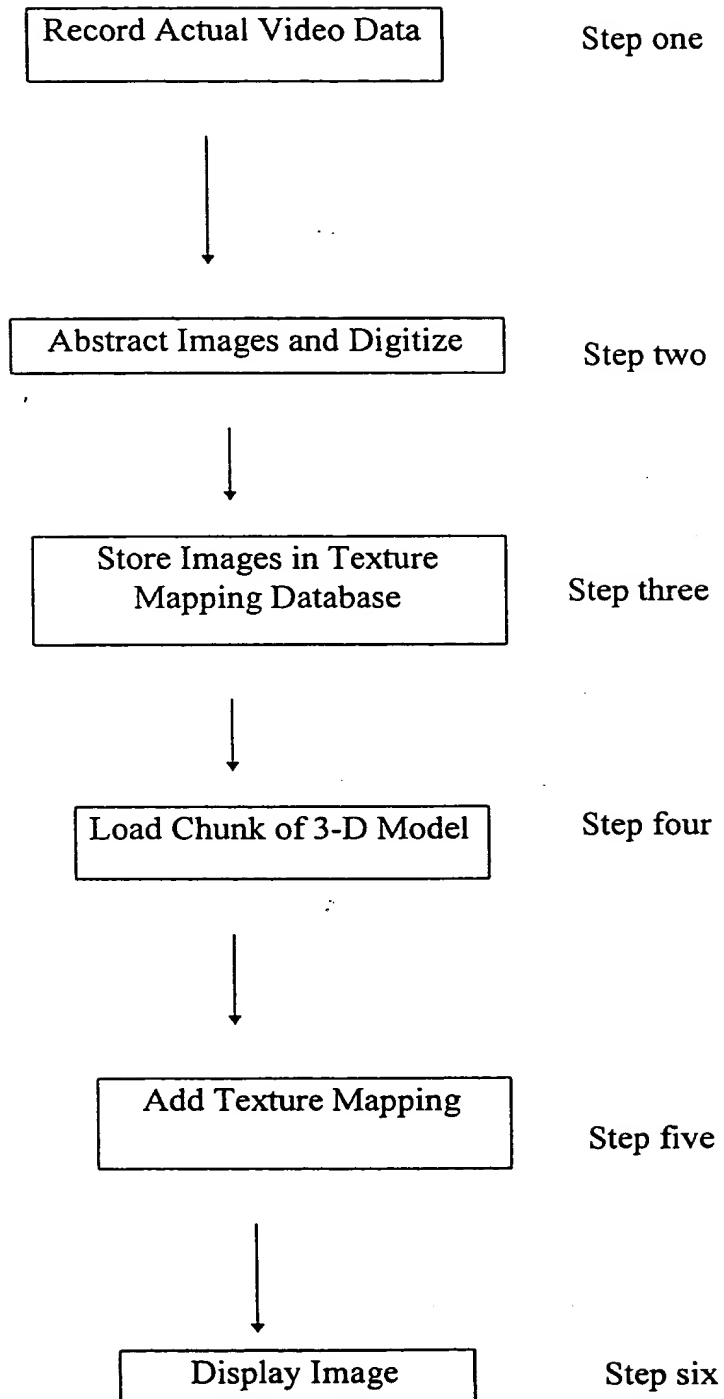


Figure 3A



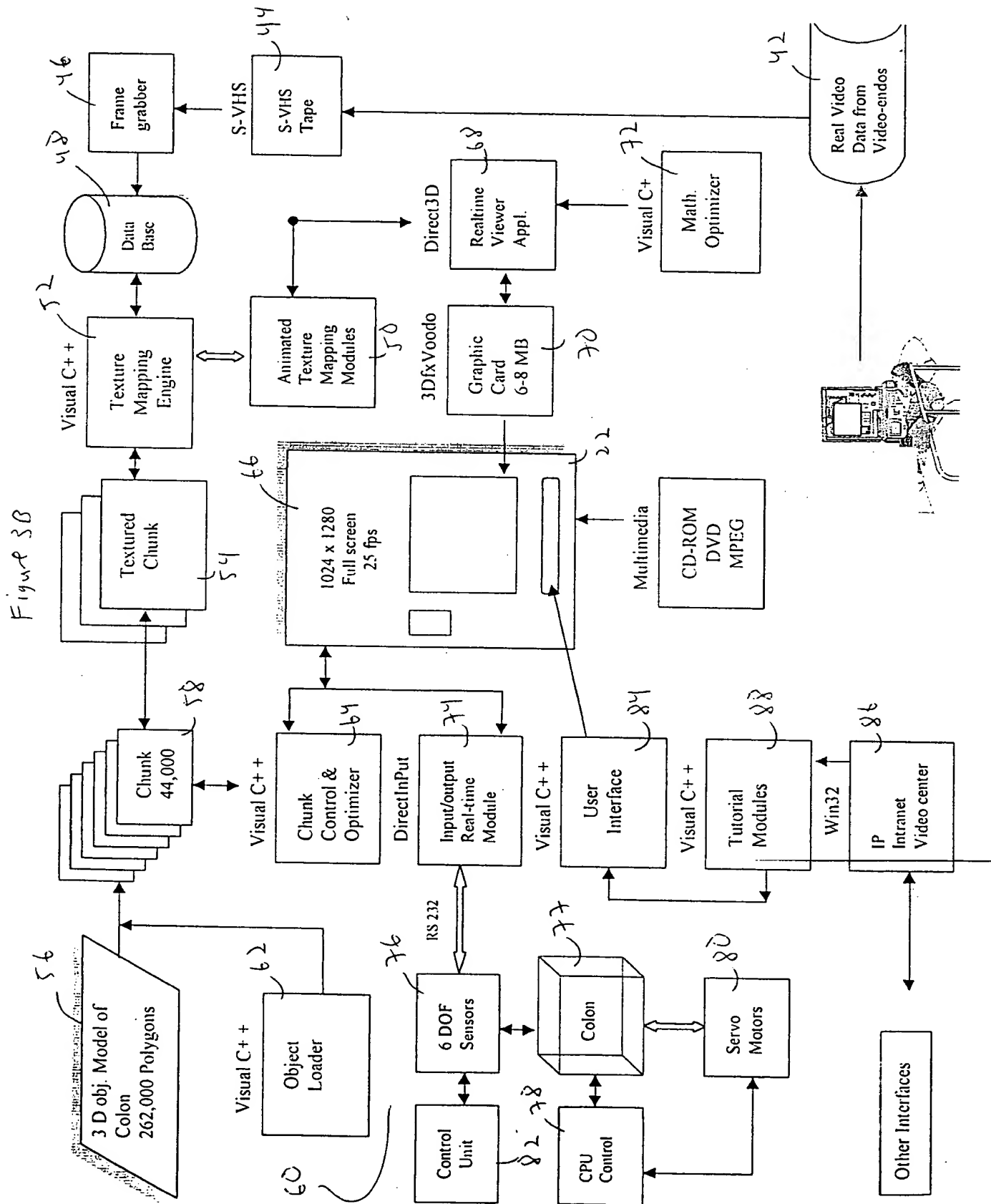


Figure 4

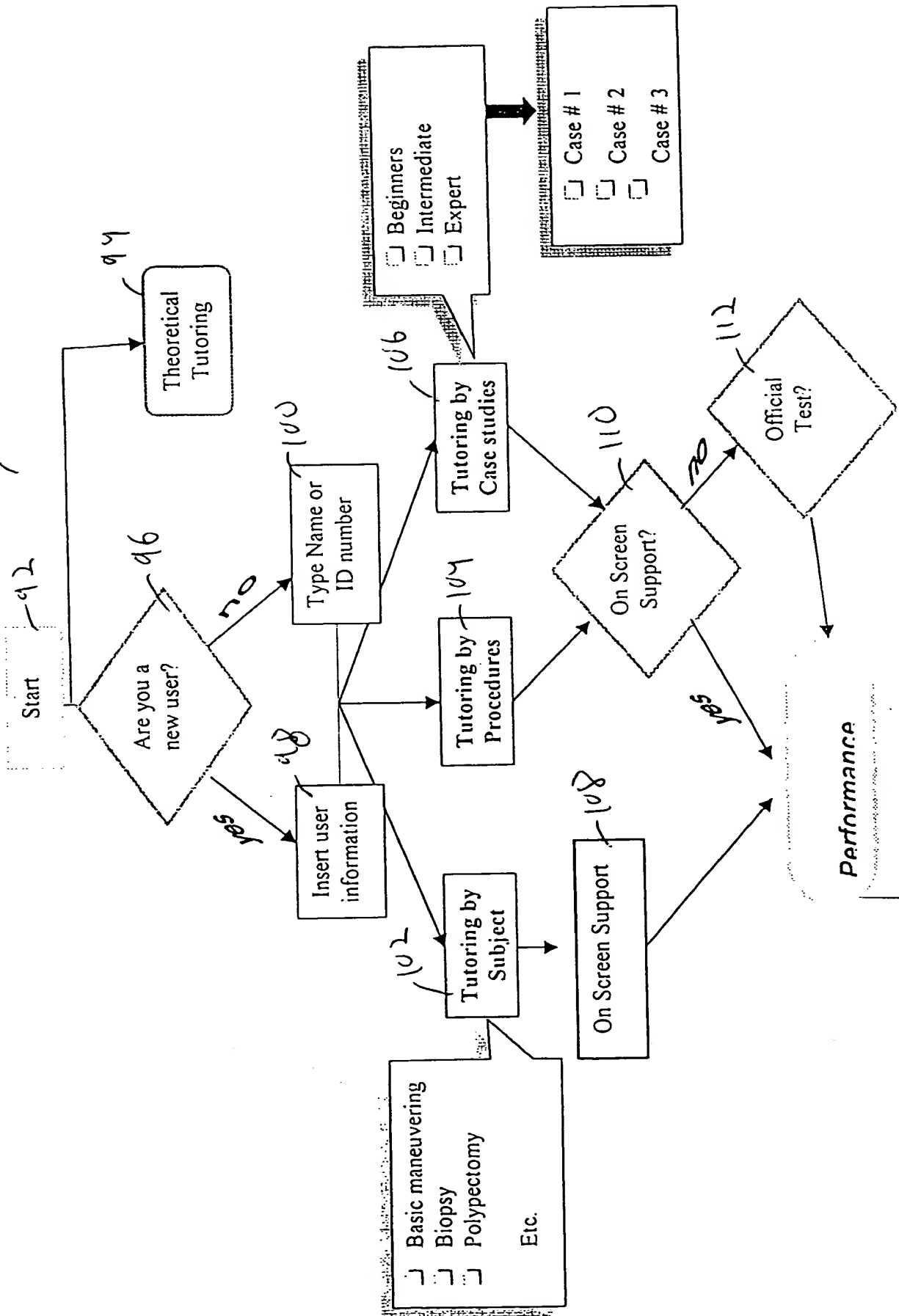


Figure 5A

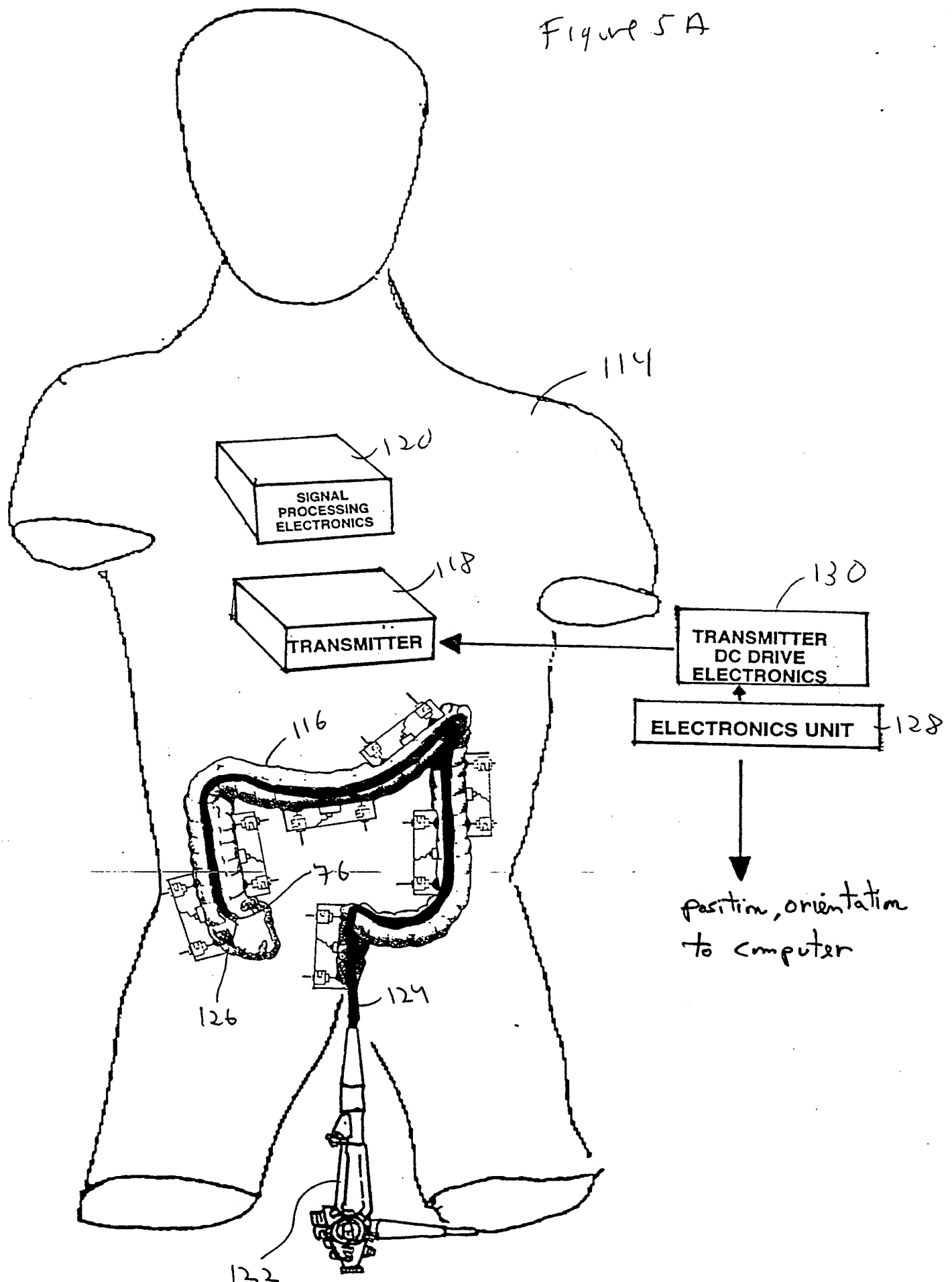


Figure 5B

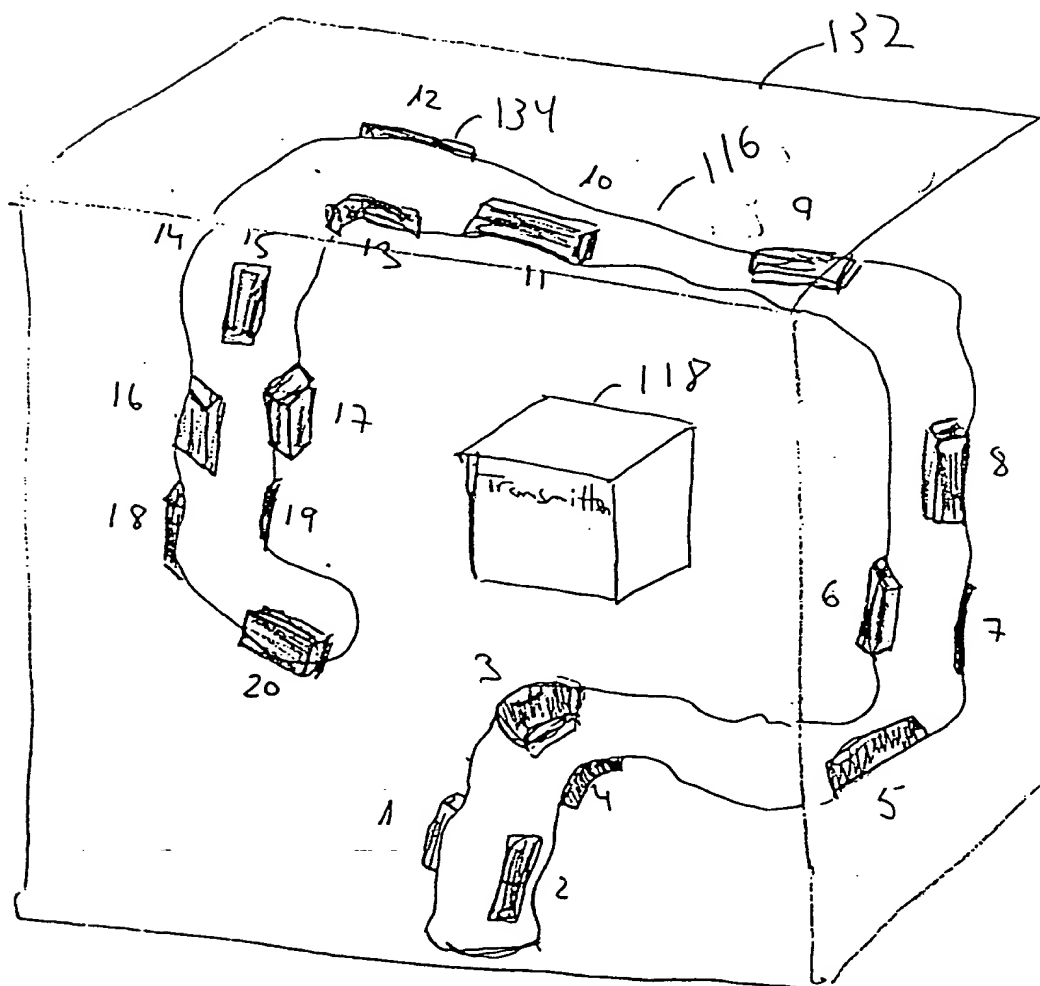


Figure 6 A

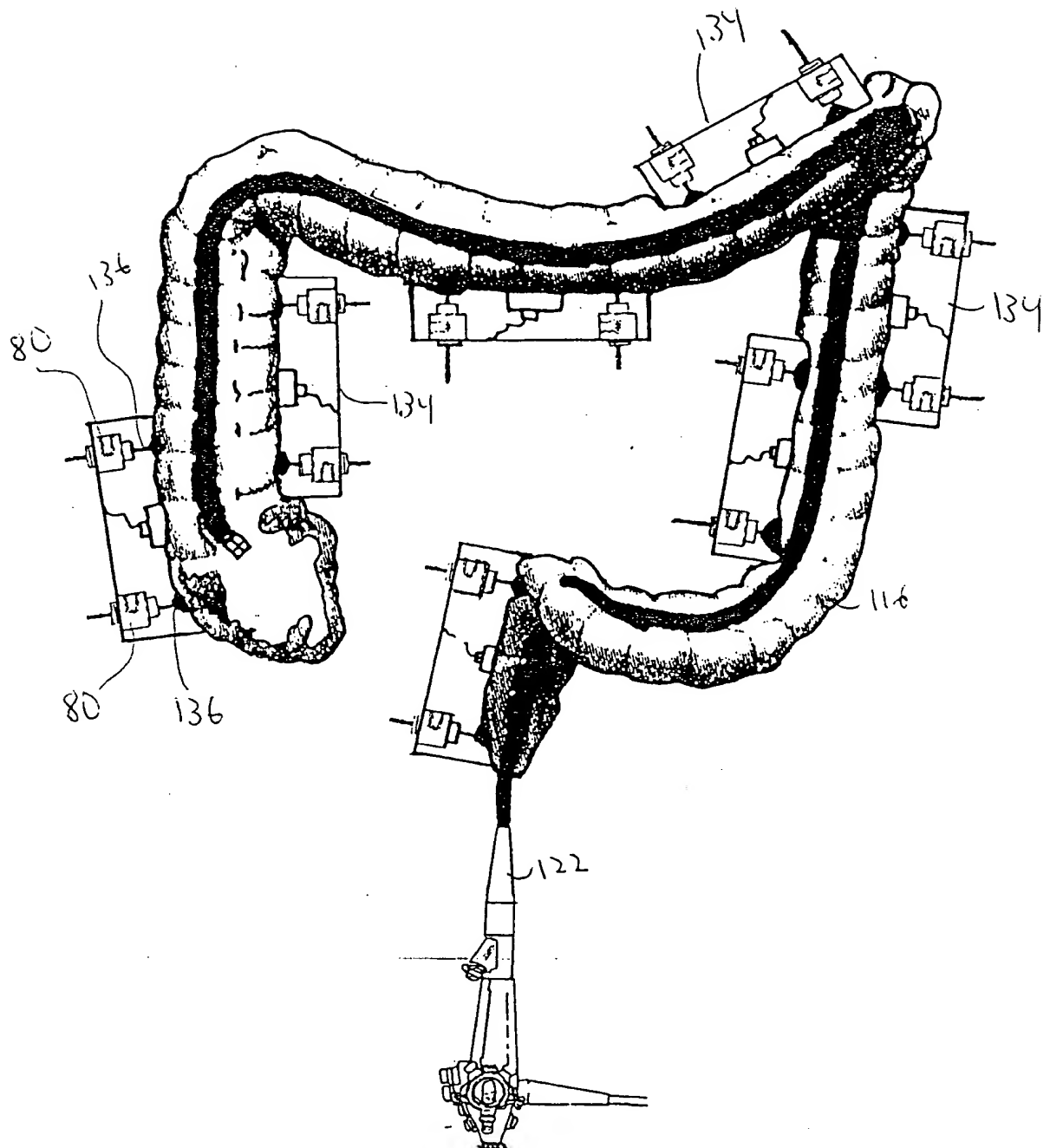
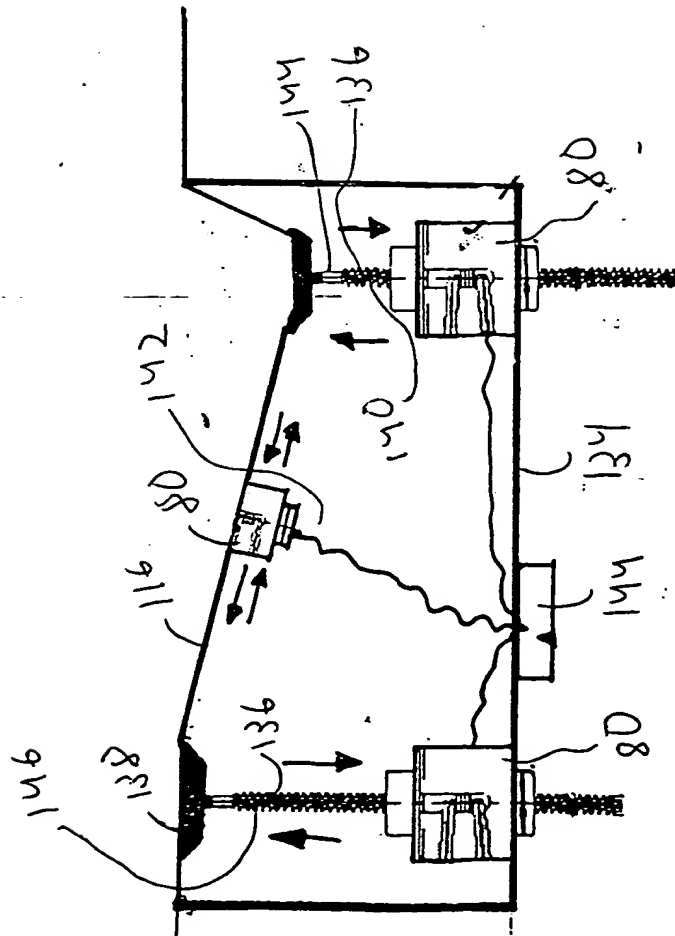


Figure 6B



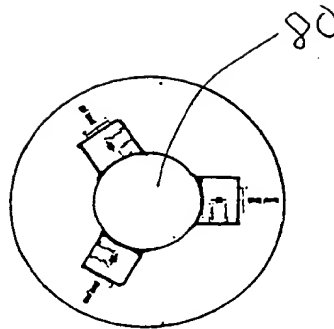
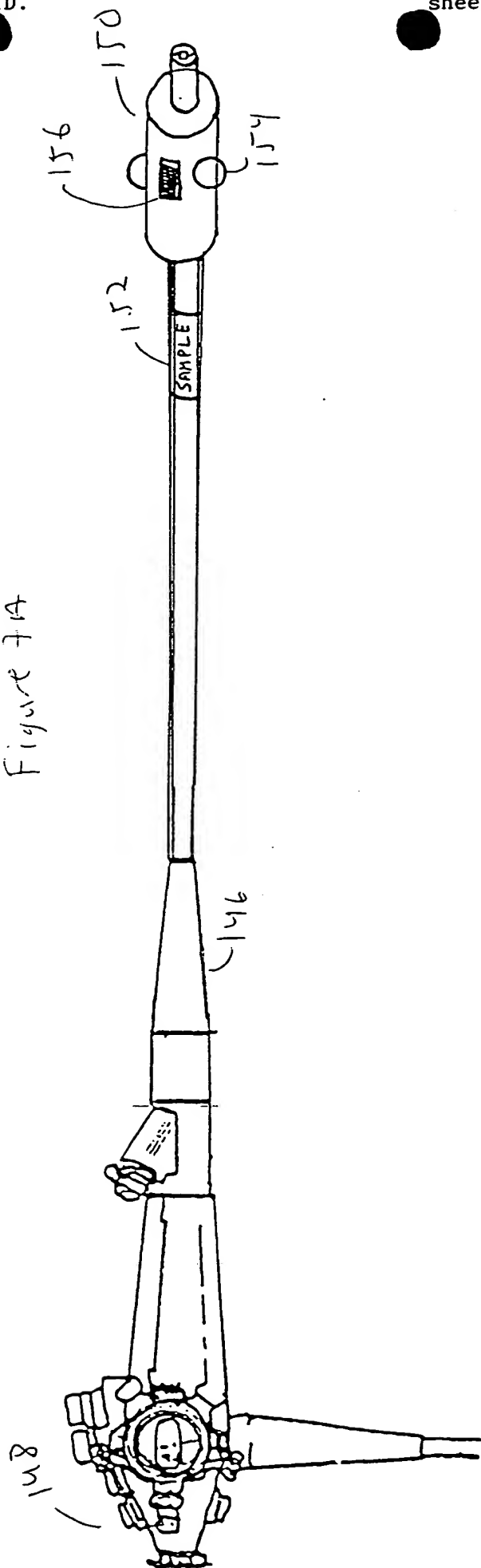


Figure 6C

Figure 7A



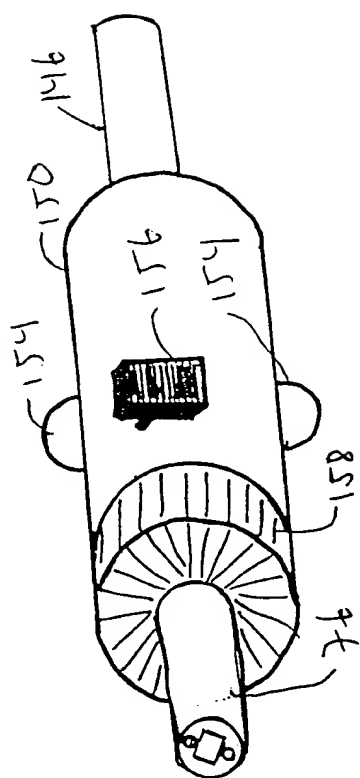


Figure 7B

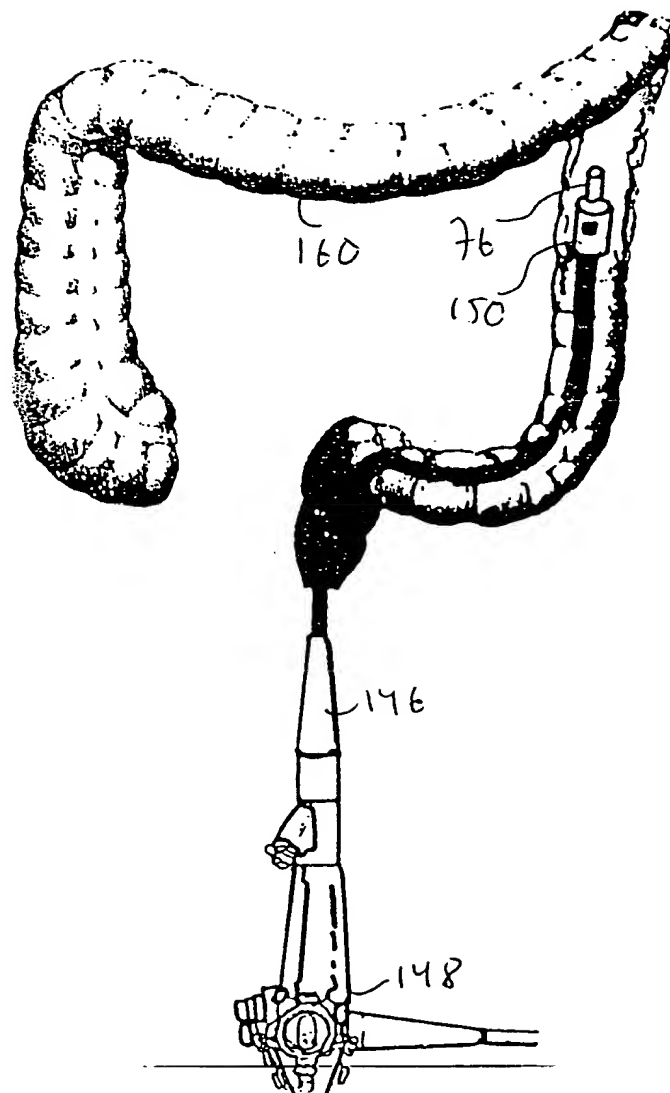


Figure 7C

Figure 7D

